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# A REVIEW OF MAJOR ISSUES RELATING TO HUMAN-MACHINE INTEGRATION IN THE DEVELOPMENT OF MILITARY SYSTEMS


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This paper discusses recurrent problems and deficiencies related to the adequate consideration of human factors, manpower, personnel and training issues in the development of military systems. It provides a brief review and a discussion of these issues from a number of differing perspectives of the varied participants in the development and acquisition community.

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# I. INTRODUCTION

The present report has evolved out of almost three years of study of the role of human factors and its impact on the process of the development of military systems. During this period, two major substantive reports (Price et al., 1980; Saywer et al., 1981), several ancillary papers, and two instructional tools for engineering managers were generated. The broad goal for all these products was to find the means by which those who manage the military system development and procurement process could more assiduously, effectively, and economically utilize the contributions inherent in human factors participation.

The present report, in one perspective, is a by-product of that effort. From another perspective, however, it represents an attempt to stand back from the myriad details of the system development process and assess the role and impact of human factors from a policy and planning point of view. The foundation for achieving the latter perspective was a collection of documents that describe the system development and procurement process; often in critical terms. The main question to be answered was: Are there recurrent problems or deficiencies in the system development and procurement process, particularly deficiencies in the utilization of human factors inputs? If so, how might the contribution from human factors be strengthened so that the total process would be improved?

## Background

At present, the military R&D community is being bombarded by critics from all points on the compass. Reverberations are heard in the mass media and the halls of Congress. For example,

in the September 1982 issue of *Harper's*, there is a short essay by Wm. S. Lind, a legislative assistant to Senator Gary Hart, entitled "Simple Tanks Would Suffice." Mr. Lind is said to represent what he calls the "military reform" movement.

While the present focus is on current issues, criticism of the military procurement process is a well-established tradition in the U.S. that goes back to the founding of the country. Even in the early days, there was vocal concern over the efficiency of provisioning and talk of incompetence, dereliction, and even corruption.

Over the years, the level of criticism has waxed and waned in rhythms linked to the level of military activity, the threat, and the level of investment. World War II was a particular watershed in this process. When the tide of battle finally turned and the U.S. and its allies seemed certain of ultimate victory, critism of any kind seemed entirely pointless and definitely unpatriotic. Furthermore, in the last stages of World War II and in its aftermath, it became increasingly apparent that one of the major factors in achieving superiority on the battlefield was the extensive application of advanced technologies of varied kinds. Nuclear weapons were only the culmination; radar, sonar, and what now appears as primitive applications of computer technology were other prominent examples. There grew out of these experiences a strong commitment to the idea that battles, and indeed wars, could be won by the introduction and utilization of "decisive" weapons.

## A Problem Orientation

The search for decisive weapons has led to a continued high level of investment in advanced technologies. Yet, it would be an oversimplification to characterize the era from the 1940s to the present as a conceptual struggle between those who would give preeminence to the weapon versus those who would give preeminence to the human soldier. Many other factors come into the equation; concepts of strategy, deployment, logistics, command structure, and, of course, cost. In any case, most observers and critics have recognized that the main issue is not human versus machine, but rather human plus machine, in the sense of the weapon as machine, and the integration of the two.

Thus, a problem for the present is how to achieve this integration. Stating the problem in this way raises several broad questions, such as:

- Are there recognizable patterns of failure of integration in our current weapon systems or those in development?
- Insofar as failures of integration do exist, is the root cause of such failures related to a lack of knowledge, a lack of managerial control, a lack of resources, or what?
- What is the most efficient approach or set of procedures that would remediate these failures and minimize the likelihood of the occurrence of similar failures in the future?

As a step toward answering these questions, it is appropriate to first achieve a general overview of the alleged deficiencies in current weapon systems. Specifically, we first must answer the question: What points are the critics making that relate

directly to failures of human-machine integration? It must be recognized that purported lacks of human-machine system integration are most often identified among a concatenation of other issues. Some critics give the human-machine integration issue a dominant role in the overall diagnosis; indeed, some critics have this issue as their singular focus. Other critics emphasize other issues so that human-machine integration is only a small component in their overall diagnosis or shows up only by inference. Thus, source and context must be taken into consideration in the attempt to construct a composite, summary analysis. Also, it is true that some sources are bound to be more influential than others, have a better claim to objectivity, or have a better claim to diagnostic competence than others in the game.

# II. APPROACH

## Topic Specification

Human-machine integration is the core mission of human factors engineering (HFE). As such, there are major areas of overlap and cross-dependency to the broader field labeled manpower, personnel, and training (MPT) in military parlance. For example, the solution of a specific human-machine integration problem--one whereby the operation of the system during a particular mission phase requires some very high-level skills--might be solved by selecting operators with high aptitude, transferring skilled operators from a similar system, training intensively, or designing-in computer aids that could "unburden" the operator. We have shown in previous reports (Price et al., 1980; Sawyer et al., 1981) how such alternative solutions can be evaluated by examining the trade-offs between the resultant criterion functions of operational capability, cost, and user compatibility.

By showing how HFE and MPT are linked one to the other and how both are linked to the still broader field of systems engineering, the prior work built a logical conceptual framework for the constructive utilization of HFE contributions by engineering managers from the beginning to the end of the system development process. The prior work also provided case studies to show that such utilization could enhance the likelihood that the result would be more effective and less costly. Thus, from a functional standpoint, we are talking about the contribution of HFE and MPT expertise to the system design and acquisition processes.

## Specific Objectives

The intended end product was a distillation of the works of critical evaluation that relate the attributes of military systems and the procedures of procurement to HFE participation in the form of R&D (studies) or direct design recommendations. This distillation was intended to be such that the priorities assigned by critics would be made clear, but of prime concern was that the emergence of consensus, if it were present, should be easily apparent.

Such a product was seen as a possible source of support for policy review on the part of those who manage the HFE/MPT enterprise within the military services and the DOD and as a possible source of pointers for program alignment and the initiation of new programs, if needed.

## Procedure

### Source Materials Acquisition

As suggested in the introductory remarks, criticizing the military system procurement process has become a widespread popular pastime. The resultant literature is very diffuse with respect to the form of publication and it is also thematically redundant. Consequently, the objective in constructing the body of documentary materials upon which the analysis would be based was to achieve representativeness of ideas rather than comprehensiveness in a bibliographic sense. Specifically, the collection of source material actually compiled should be regarded as a sample representation of a larger set.

Moreover, it should be noted that the sample selection procedures were not random. One constraint was recency. Only a few items dated before 1980 were included and there was a denotable reason for each such exception. Another constraint was relevance in the sense that preference was given to items that specifically addressed the question of human-machine integration: Still another constraint was prospective impact. While impact sometimes links to the vehemence of the author (e.g., the works of Spinney and Fallows), more often it is associated with the formal administrative responsibility of the source (e.g., the General Accounting Office or the Defense Science Board). Finally, inclusion was also based on accessibility in the particular sense that no classified material was used.

Two bibliographic search mechanisms were employed: DIALOG, which provides broad coverage of all the open scientific and technical peridical literature and of the holdings of the National Technical Information Service, and SORTAM, the proprietary computerized search system at BTI. Materials were also provided directly by the COTR from the ARI holdings of technical reports and U.S. Army internal documents. Finally, an ordinary catalog search of the monographic holdings of the University of Maryland was conducted which identified nine clearly relevant trade publications.

The final sample was composed of 72 government reports and journal articles plus the 10 books. The books were not blended into the main body of source documents for reasons that will be discussed below.

## Analysis

As suggested above, the final product was intended to be a review of the relevant literature. Several approaches are feasible in conducting such a review. We adopted a three-component technique as follows:

1. An initial characterization of the "posture" of the critic or evaluator: Who is taking this role and what is his/her thematic focus or coverage?

2. A characterization of the critic's target: Is it a matter of displaced priorities, lack of appropriate expertise, mis-directed policies, failure to comply with standing SOPs, or what?

3. A focus on discrepancies or failures (i.e., "issues") that fall within the technical competence or responsibility pattern of those who are providing HFE/MPT support for the military system development enterprise.

Also, as an inferential rather than an analytical step, an attempt was made to delineate knowledge gaps that could impair the quality of HFE/MPT support and that could be filled by R&D under the HFE/MPT rubric.

Each of these steps is described in more detail below.

## Classification Scheme

The raw material consisted of a relatively small but very heterogeneous body of documents. The first step in the organization of such material that also would be responsive to the objectives stated above was a classification step.

Given that topical coverage was not the only feature with which we were concerned, a faceted classification scheme was appropriate. The following facets were used for pre-analytical coding:

1.0 Source (the "critic")

1.1 Individual or ad hoc collaboration
- 1.1.1 In-Service Military
- 1.1.2 In-Service Civilians
- 1.1.3 Retired Military
- 1.1.4 Private Civilian
- 1.1.5 Congressional (including staff)
- 1.1.6 Contractor (including grantees)
- 1.1.7 Other or Mixed

1.2 Enchartered Panel, Committee or Task Force
- 1.2.1 In-Service Military
- 1.2.2 In-Service Civilian
- 1.2.3 Private Civilian
- 1.2.4 Congressional
- 1.2.5 Contractor
- 1.2.6 Other or Mixed

2.0 Thematic Focus

2.1 Branch
- 2.1.1 Army
- 2.1.2 Navy
- 2.1.3 Marines
- 2.1.4 Air Force
- 2.1.5 All or Mixed

2.2 System

2.2.1 Ordnance

2.2.1.1 Hand-Held

2.2.1.2 Crew-Operated

2.2.1.3 Strategic (e.g., nuclear)

2.2.2 Vehicles (Combat)

2.2.2.1 Land

2.2.2.2 Surface Ship

2.2.2.3 Amphibian

2.2.2.4 Subsurface Ship

2.2.2.5 Aircraft

2.2.2.6 Missiles

2.2.2.6.1 Tactical

2.2.2.6.2 Strategic

2.2.3 Support

2.2.3.1 Communications/Information Processing

2.2.3.2 Testing/Training

2.2.3.3 Logistics

2.2.3.4 Personal Equipment

2.2.4 Mixed or General

3.0 Criteria

3.1 Cost

3.1.1 Procurement/Acquisition

3.1.2 Ownership/Support/Upkeep

3.1.3 Life-Cycle

3.2 Effectiveness

3.2.1 Lethality

3.2.2 Vulnerability

3.2.3 Reliability

3.2.3.1 Maintainability

3.2.4 Adaptability (Capacity)

3.2.5 Compatibility

3.2.5.1 Physiological

3.2.5.2 Intellectual

3.2.5.3 Attitudinal

3.3 Mixed

4.0 Problem Etiology

4.1 Administrative

4.1.1 Structural

4.1.2 Procedural

4.2 Political (Policy)

4.2.1 Ideological

4.2.2 Inertial (Historical Precedence)

4.2.3 Suboptimum Compromise

4.3 Economic

4.3.1 Underfunding

4.3.2 Mis-allocation of Resources

4.4 Technological

4.4.1 Obsolescence

4.4.2 Hyper-sophistication

4.4.3 Specific Engineering Design Errors

Content Synopsis

Each of the 72 items in the main sample were coded according to the preceding scheme and an analytic summary was also written for each. In preparing the analytic summary, readers were instructed to focus on issues and solutions. The conceptual framework can be likened to medical diagnosis and treatment: What did the author(s) indicate was wrong and what should be done to remediate the process? If the author presented

an ideal scenario for the system procurement process, analysts were told to capture such propositions. Similarly, they were to be particularly alert to assertions about the stage or phase of the developmental sequence that was characterized as being weak or deficient.

Finally and most important, analysts were instructed to identify specifically what the author(s) proposed as a cure: What remedial steps or reforms were recommended?

Thus, the content analysis procedure consisted of summarizing the content of the articles and technical reports in two ways: (a) by a structured classification scheme, and (b) by a semi-structured abstract.

# III. RESULTS

## Critics and Target Audiences

Characterization of the authors as "critics" may seem a little harsh, but it is appropriate to the extent that the reviewed documents directly or indirectly point to inadequate human-machine integration in military systems. The writers represent the entire spectrum of interested parties in the systems/R&D community, ranging from private contractors to service laboratory scientists and DOD policy makers; some commentary from outside this professional milieu also was included (e.g., public opinion, GAO reports). From an organizational standpoint, the numerous concerns voiced frequently were directed at all of the Armed Services and/or at the DOD itself. The systems focus was most often generic, although in a few reports (e.g., case studies) specific systems were alluded to or discussed in some detail.

## Document Overview

Unfortunately, one general characteristic of the literature on military system development that cannot be ignored is the lack of conceptual consistency within it. For example, some authors tended to use such terms as "readiness," "effectiveness," and "capability," as if they were synonymous. Such a circumstance pushes the reviewer in the direction of greater subjectivity of interpretation. However, on the positive side, most of the documents that were analyzed did describe system deficiencies and discussed the apparent reasons for such deficiencies as well as the means of correcting them. A wide variety of HFE/MPT

problems were discussed, and these in a sense constitute the "raw data" of this analysis. The remainder of this section describes specific examples of author's commentaries. The descriptions, in turn, will serve as the foundation for an extended discussion of the generic, recurrent issues and the possible courses of action for addressing these issues.

The HFE/MPT areas discussed below undoubtedly are not exhaustive and definitely are not wholly independent. Separate discussion of them nevertheless will help to illustrate the problem areas in a coherent fashion and the overlap between these areas, both in the nature of the deficiencies and the underlying causes, will help to frame the discussion of the basic issues to be presented in the next section. The deficiencies are presented essentially as summaries of the main points made in the reports. Immediate causative factors identified by the critics often can be tracked back to higher, broader levels of influence and scope (R&D community, defense community, Congress, etc.). The emphasis in the present case is on the R&D community--a more attainable target for this effort. Nonetheless, issues at a higher level of priority are of great importance and have not been overlooked.

## Human Resource Requirements

Both the accuracy and the implementation of human resource requirements represent areas of great concern among various critics. Kerwin et al. (1980) and the U.S. General Accounting Office (1981f) assert that such requirements frequently do not emerge from early analyses in accurate, quantifiable ways. In addition, they rarely are translated into meaningful contractor requirements during procurement. Likewise, the meaning of

manpower *requirements* data and manpower *demand* data usually is not conveyed to the Congress, the consequence being an inadequate congressional understanding of our war and peacetime manpower needs. The consequences of unreliable and uncommunicated MPT requirements are obvious enough: high costs, uncertain recruiting needs, and general unpreparedness. The cause of the problem is multifaceted. Kerwin et al. (1981) point out that in the Army, deferral of Integrated Logistics Support (ILS), waivers, and bureaucratic inertia usually preclude timely integration of requirements data. Bergmann (1980) states that the pressure to field technologically new systems at a fast pace creates a situation in which the requirements for highly skilled personnel are greater and correspondingly more difficult to predict. He feels that the Office of the Secretary of Defense (OSD) should project the impacts of future systems upon manpower demands and that the services should promote design and support concepts that minimize manpower demands. The latter opinion is shared by Baker (1980) and Baker and Shields (1981), who argue that the interactions of the major elements (design, training) among the personnel subsystem of Army systems frequently are ignored; that is, such elements often are studied in total isolation from one another. Finally, Weddle and Fulkerson (1980) emphasize the cost impacts of underestimating manpower requirements and discuss the effort by the Navy's HARDMAN office to develop a 15-year requirements projection methodology that will facilitate the forecasting of manpower needs largely on the basis of hardware acquisition schedules.

## Recruiting and Retention

Both the recruiting and retention of qualified personnel are perceived to be acute problems and hence have received wide attention. During his tenure as Secretary of Defense,

Harold Brown (1981) emphasized that they constitute one of our most pressing manpower problems throughout the Armed Services and that the situation cannot be expected to improve significantly without strong initiatives, especially in light of an anticipated 20 percent decline by 1992 in the pool of eligibles. He points out, for example, that in the Navy since 1976 there has been a constant shortage of petty officers numbering approximately 20,000. Service-wide shortages are particularly acute in the speciality areas such as engineering, medicine, flying, and nuclear service, a problem also recognized by Meis (1981) and Zech (1981). This skill lag is apparent whether considering either recruitment or retention (completion of first term or reenlistment after first, or later, term). The overall percentage of high school graduates who enlist is declining, and this trend is especially noticeable in the Army, where the percentage has dropped precipitously from 78 to 54 percent between 1978 and 1980 (Merriman & Chatelier, 1981). However, this negative trend might be partially offset by a recent surge in the Army first-term reelistment rate.

The ultimate manifestation of the problem may be reduced effectiveness and readiness of existing and new systems. As Baker (1980) explains, about 200 additional materiel systems are scheduled for the Army's inventory during the present decade. In general, the available manpower supply does not meet the requirement for substantial technical skills necessary to support such systems, many of which are quite sophisticated. However, there already are some visible signs of the kinds of pressures exerted by qualified personnel shortages. An increasing trend in recruiting malpractice and abuses reported by the U.S. General Accounting Office (1981e) is especially symptomatic of the problem. Survey data indicate that increased

pressure on recruiters to meet high quotas has increasingly led to such practices as distorting service benefits and falsifying/ omitting biographical information of potential recruits. Another manifestation of potential personnel shortages, as pointed out in another General Accounting Office report (1981d), is that instituting the All Volunteer Force (AVF) has shifted much of the mobilization responsibility to the National Guard and Reserve forces, and their readiness level is subject to some doubt, if not outright skepticism.

To varying degrees those writers concerned with the problem of recruiting and retaining capable personnel have proposed both etiological factors and remedial courses of action. The AVF concept, of course, is mentioned as a causal factor (U.S. General Accounting Office, 1981d). Also, insufficient attention to both the overall quality of military life and the need for programs aimed at upgrading personnel educational and skill levels have been mentioned (Brown 1981; and Meiss, 1981). The basic problem is that of attracting to the services people of high ability and maintaining their interest after they are enlisted.

## Personnel Selection, Classification, and Utilization

The important questions in this area concern the ability of the managers of the personnel subsystem to effectively predict personnel performance and then distribute personnel to jobs so as to maximize the use of their abilities. Brown (1981) says that many present paper-and-pencil tests are not valid predictors of actual job performance in the services and are useful largely for predicting training performance and serving as indicators of recruit aptitude fluctuations. High school degree status to some extent predicts the probability of

retention over the first few years of service, but the decreasing manpower pool will probably exert greater pressure upon all predictors, including this one. Shields and Baker (1981) point to the need for translating real performance requirements in the Army into behavioral criteria for job success in the Army; and, given the always-shifting systems environment, a more effective computerized decisionmaking system is necessary for meeting the objective of effective personnel assignment. Two other reports (House Committee on Armed Services, 1982; and Tice, 1981) also discuss the need for a data base regarding the relationship of both biological factors and test scores to effective job performance. The Armed Services Committee, in particular, is very critical of the DOD's past efforts, stating that it is incumbent upon the DOD to invest sufficient funds for this purpose.

Inattention to the development of better predictors is by no means the only problem in this area. According to Carroll (1980), reporting on the Multiple Launcher Rocket System (MLRS), the combination of unfinalized MOSs and changes in aptitude subtests may produce uncertainty about MOS skill levels. Also, Nauta (1981) states that personnel assignment systems are inadequate; and Friedman (1981) points out that in the case of the Army's Remote Piloted Vehicle (RPV), different areas are independently drawing personnel from the same personnel pool. Finally, a report by Nauta and Bragg (1981) indicates that the Armed Services exercise no centralized control over personnel assignments and that even after personnel are assigned, they often spend significant amounts of time on non-MOS related duties.

## Training Effectiveness

The broadest statement on this subject was made as part of a Department of the Army report (1981) on soldier/machine interface requirements. As in the case of both HFE and manpower, training requirements often are watered down, if not waived, during systems development. Also, the lower educational status of present-day recruits has made the earlier training philosophies obsolete. Another problem is the poor synchronization of training and the fielding of new systems. Trained personnel are frequently rotating out before a system is ready to be manned. The report also recommends that the "representatives" of the combat arms user who participate in operational tests of new systems should in fact be *representative*--their skill level and experience should correspond with that of the ultimate users.

A subject that attracts much attention from commentators is that of training devices and aids. The scientist-administrators in the Office of the Under Secretary of Defense for R&E (1980) have expressed great enthusiasm for learning aids and games that incorporate interactive audio-video capabilities (e.g., speech recognition, speech synthesis, and interactive computer technology). A memorandum (1979) for the Deputy Assistant Secretary of the Navy (Manpower) praises the work in training technology conducted at the Navy's Air Traffic Control School and Naval Training Equipment Center and recommends that this type of initiative be embraced by all of the services.

Another report (Fletcher, 1981) recommends the use of low-cost, portable training aid devices as a high priority item for increasing readiness. However, he warns that such devices should be designed with the eventual user in mind, not just the trainee. This warning seems to be an implicit criticism of those who develop training programs but who lose sight of their

ultimate purpose. Another criticism in this area is leveled in a Department of the Army study (1981), which points out that training device efforts often resemble HFE efforts: "Too little, too late."

## Test Equipment

In the area of test equipment, problems directly associated with high technology frequently are mentioned. Smith (1981) states that test equipment used in maintenance troubleshooting frequently breaks down. That is, the complexities of both the test equipment and the system being tested are contributory factors. Nauta and Bragg (1981) make a similar assertion about built-in test equipment (BITE) and automated test equipment (ATE). They emphasize problems related to inaccurate equipment and associated false readings resulting in multiple removals of line replaceable units (LRUs). In a similar vein, Ostovich (1982) says that the technical manuals used with a number of systems (M1 tank, U-H Helicopter, TACFIRE, and the DAS Support Computer) are of very poor quality. Another report by the General Accounting Office (1981) says the same thing in egard to the M1 tank technical manuals, adding that test equipment, diagnostic equipment, and manuals often are *incompatible*.

## Design and Human Factors Engineering

A great number of reports have expounded on the poor HFE incorporated in the design of various systems, and a few will be mentioned here. A report by the U.S. General Accounting Office (1981b) focuses upon the costs, management, and effectiveness of a number of systems in the different services, and the AH-64 helicopter draws some fire in regard to HFE problems. Excessive vibration presents a potential crewmember fatigue problem, and

large smoke emissions reduce crew visibility. Acquisition management and procedures are faulted, the piecemeal development of different system components, in particular, receiving criticism. A U.S. General Accounting Office report (1981c) and a briefing package (Ostovich, 1982) criticize the M1 tank on both operations and maintenance design (e.g., awkward gun arrangement, lack of maintenance accessibility). Ostovich says, nonetheless, that operations and maintenance personnel "liked the new system." He also says that "complexity" is not readily definable and that the HFE problems are not necessarily related to high technology, a favorite target for critics from outside the defense community. Keith (1980), in a memorandum shares the view that complexity is not easily defined. Finally, a Naval Research Advisory Committee (1981) discusses a host of HFE design problems on numerous Navy systems (primarily surface vessels); among them the following: operator overload, lack of system/subsystem standardization, poor maintenance accessibility, unrealistic anthropometry, and insufficient job aids. The problem is attributed to the dearth of HFE programs in the surface ship development community. They recommend that the surface ship designers follow the example of the Navy aircraft design community or the Army. A number of other reports (Department of the Army, 1981; Price, 1981; and Price et al., 1980) discuss the basic reasons for HFE deficiencies throughout military systems, and, as in the case of the other human resource areas, fingers are pointed at the procedures, methodology, tools, and the attitudes of systems developers.

## Back-Up Analysis

As indicated previously, book sources were also reviewed. These sources were not classified or synopsized in the same way

as the technical report sources were. Rather, they were read after the other sources had been analyzed to provide a form of cross-validation and coverage check on the main analysis.

There are some crucial differences between the two sets of source materials. For example, as already indicated, the bulk of the primary source documents for the present review was technical reports. In a functional sense, such materials are mainly a vehicle for interior communication among members of the defense community. While it is an open literature, it is basically one in which a few defense professionals are discoursing with their professional colleagues. There are other literatures that cover some of the same topic matter, however. One such literature is composed of so-called trade publications issued by commercial or academic publishing houses and intended for a much wider lay (i.e., non-professional) audience than are technical reports. Defense professionals often author such books--at times, it seems, in order to take their point-of-view into a larger sociopolitical arena.

The obvious question that comes up is: Is what is being said to this broader audience different in tone or content from what is being said within the professional community? A second, more pointed question is: Do these discussions (of the basic topic of military systems development) allude in any way to the issue of human factors or to manpower, personnel, and training problems?

The general answer to both questions is: No, with some qualifications. One of the qualifications has to do with stylistics. It is not surprising that the presentations in the tradebooks tend to be less tightly structured and to use a less

technical vocabulary. Also, the value criteria are more diverse. For example, it is not uncommon to raise the level of trade-off considerations from that of a contest between two or more system configurations to that of a contest between weapons procurement and some other social goal. Other presentations approach the system development process from the point of view that simply assumes that the process is rife with waste and fraud and looks to the destruction of the whole procurement apparatus. (Sources of these kinds are not actually cited and were not reviewed in depth because the patent lack of relevance to the specific problem at hand.)

Somewhat surprisingly, positions that could be called anti-technology are very scarce. Even the harshest critic of military "managerism" (Cincinnatus, 1981) ends up by recommending that lessons learned--e.g., from field experience with new weapons systems--be recorded in a *computerized* file which could come to serve as the corporate memory of the Pentagon!

There is also a particular characteristic of critics of current procurement practices to use "insider" arguments against the defense establishment. For example, public testimony that highlights "problems" is usually intended by the testifier to provide the justification for funds to support the search for a solution. The critics take these same assertions about problems as symptoms of the bankruptcy of existing systems. In this regard, we find the failure of the mission to rescue the hostages in Iran as a vehicle for denouncing any and every facet of military operations--the equipment was shoddy, training was inadequate, planning was poor, command structure was bizaare, communications were confused, etc., etc.

Finally, it is truly ironic to follow the arguments of a critic like Kaldor (1981) who berates the military procurement people and their counterparts on the industry side for introducing such a high level of technological sophistication and complexity into a wide range of weapons--and then goes on to suggest that the solution to the problem lies in the development and deployment of more varieties of precision guided munitions (PGM). The irony comes from the fact that PGM often represent a level of technological sophistication even higher than that in the many "advanced" weapon systems that are criticized for that attribute.

The discussion of human factors is sparse indeed, and when the topic is raised it tends to be at the broadest level--e.g., all volunteer vs. draft or the lack of support for or effective utilization of the reserves. The specific issue of human-machine compatibility is never mentioned in any of the nine volumes reviewed in depth. While it is conceivable that this modest sample of literature is not representative, it is suggestive that the people who are likely to invest their time in extensive comment on the system development and procurement process are not preoccupied with the problem of the human-machine interface. When specific systems are used as case examples, even mission effectiveness is not the primary criterion; cost is (because of the concern for budgetary competition from non-defense programs).

It is illuminating to go back to the 1960s via the Mansfield volume (1968) to renew one's perspective about how the issues that are salient with respect to defense-related R&D and systems procurement shift over time. It is clear that the 1960s were a time when the issue of defense economics was even more prominent

than that issue is today. For example, whether or not to impose cost-effectiveness analysis on decisionmakers was still being debated. While present conditions do not necessarily support the belief that cost considerations have come to singular dominance in defense procurement decisions, the utility of a rationalistic or quasi-rationalistic set of mechanisms for cost analysis and projection as part of the formal deliberative process is no longer debated. Cost factor constraints may be circumvented or even disregarded in some programs but this is done on the basis of presumptively overpowering considerations--political, strategic, or otherwise; not because the decisionmakers are unaware of the economic consequences or of methods for assessing such consequences.

In the 1960s, the emergence of questions focused on the effectiveness of conventional weapon systems was incomplete. Performance deficiencies that would become apparent as a by-product of the Viet Nam situation were not yet visible. More particularly, the issue of human-machine compatibility was almost completely supressed. The peculiar problems engendered by the juxtaposition of advances in technology and changes in the human resource base were not yet recognizable. The investment in HFE--either as system specific design participation or as non-system specific research--was approaching a low ebb. No one then was able to anticipate that the interaction of system and human operator/human maintainer could be a significant source of variance in the actual outcome of military engagements.

Given the prominence of the discussion of cost control methodology that began in the 1960s and the continuing concern for budgetary competition, one might conclude that the only way to bring human factors into reasonable saliency in the ongoing

public discussion of military systems development and procurement problems would be to link the human-machine interface issue more tightly and strongly to the cost factor.

## Underlying Causes

The problem areas underlying the HFE and MPT deficiencies discussed in this section may be characterized in terms of a variety of factors existing in the broader military and civilian communities, as well as in the R&D community. Although the thrust of the present report is toward the latter, some reference to all levels of influence is necessary because of their cumulative effects upon systems development and operation.

### The Broader Military and Civilian Community

There can be little doubt that the vagaries of political, economic, and technological change have added greatly to the difficulty of the systems acquisition process and diminished our ability to operate new systems. Political concerns often dictate not only the general nature of military systems to be developed, but in some cases specific systems as well. National policy, ideology, and vested interests all play a role in the political arena. Consequently, a given system under development may not be the most viable one nor that which the responsible armed service really wants. Also, public policy greatly affects the availability of resources. The elimination of the draft, for example, has effectively reduced the manpower pool and uncertainty in regard to funding has at times made the development and support of systems a chaotic process.

Technological change appears to be another factor contributing to the difficulties confronted in building and manning new systems, although nobody seems to agree on exactly why this is so. Some parties claim that "complexity" is the problem, while others state that there is little consensus on what this term means: it is used as a smokescreen. However, one thing is clear. Critics assert that technology sometimes is advocated largely for its own sake, and human performance problems associated with new technology often are difficult to anticipate.

One other thing is apparent as well: variability of missions, both within and between the Armed Services, appears to influence systems development problems and the support process substantially. In the aircraft systems developed by both the Air Force and the Navy, HFE and MPT problems seem to be held within reasonable bounds. On the other hand, Naval surface vessels and a variety of Army systems are inundated with such problems. In the first case, the combination of old traditions, reliance upon superfluous manpower, and the great variety of functions (transporting, maintenance, crew housing, etc.) associated with ships is probably an important factor. In the Army, the diversity of interactive systems seems to engender many of the human-related problems. Not only are there great difficulties related to systems interoperability and standardization, but the organizational network established to support the profusion of systems reflects these problems as well.

## The Military R&D Community

Although this community is affected greatly by those influences discussed above, there are more specific, and possibly more malleable, problem areas which the critics have alluded to. These are the "common denominators" which have

emerged from the discussion of all the personnel subsystem areas. At the most basic level is the attitudinal factor. While HFE, for example, is increasingly recognized as at least necessary at some point in development, it too often is considered a costly imposition, and consequently important requirements for HFE are waived or delayed. In such cases, contractors do not include such considerations in their bids and thus they are not reflected in the eventual system. Procurement policy, of course, is intended to assure the incorporation of all important requirements, but the organizations responsible for developing systems do not reward proper attention to the personnel subsystem areas. One's career is rarely affected by the taking of shortcuts in this area.

Many of the obstacles encountered in the application of HFE and MPT are due to the complexity of the organizational process. In many cases, critics have pointed out that there exist wide gaps between the researcher, the ultimate users of military systems, and those who develop them. Thus research findings are not communicated to developers in a timely fashion, and user requests frequently are unrealistic. Also, related systems and subsystems often are developed by different groups having minimal communication.

A number of other fundamental problems in the R&D area have been mentioned. A lack of thorough acquisition planning is the subject of many of the critics. Insufficient contractor monitoring, poorly planned test and evaluation, and inadequate logistical analysis are frequently mentioned. Also, inadequacies in forecasting methodologies have received much attention.

Some critics charge that operational tests in particular are often under the control of groups that have a vested interest in the outcome. There is no counterpart to the Underwriter's Laboratory for military systems, much less a Consumer's Union. While the field test process need not be adversarial, steps could be taken to make the goal of objectivity more apparent and to protect those who might render negative conclusions on the quality of a system that had powerful political backing.

## Discussion

### Conceptual Concerns

At the broadest level, two major conceptual concerns emerge from an analysis of the body of commentary on the weapon systems development process. First, there appears to be a problem in the clarity of the relationship between the process, as such, and the product that comes out of the process. A biological metaphor might be apt in this matter: that is, healthy mothers give birth to healthy babies. To put it more cogently, it is unlikely that a high quality system can be produced by a faulty development program. If this commonsensical proposition is accepted, the implication is that if we do acquire some systems with major design flows, our attention ought not to be focused so much on the flaws in the system as on the flaws in the development process.

Such a perceptual focus leads to the second broad conceptual concern. That is that the elementary value trade-offs that are inherent in the development process are routinely ignored. For example, it is an elementary observation that in most productive

processes there is a reciprocal relationship between speed and accuracy: the faster the pace, the greater likelihood of error. Thus, design deficiencies are more likely if the development process is rushed, as it often is.

A slightly more subtle trade-off is manifest in the relationship between purchase price and upkeep costs. Again, to be more cogent, pennies saved by austerities imposed on the early stages of the development process are out of portion to the risk of very large dollar costs for maintenance, or retrofit, or both on the systems after deployment.

Another elementary trade-off, and possibly the most important, is that between technological sophistication and what might be called "battle-worthiness." Some commentators allege that as a consequence of a fixation on fielding miracle weapons--systems that would provide a decisive superiority in lethality, for example--intolerable sacrifices are made in areas such as operability, maintainability, and reliability; not to mention cost. This line of argument also ties into the so-called "tooth vs. tail" controversy. It is alleged that the hyper-sophisticated weapon systems require such an elaborate support capability that the soldiers who should be engaged in combat are instead engaged in provisioning work.

One of the reasons that sophistication vs. ruggedness trade-off is important is that it may be false. Certainly, the "tooth vs. tail" argument can be turned upside down. That is, it can be asserted that if the "tooth" is more effective, the fewer soldiers exposed to direct contact with the enemy, the better. Mathis (1982) has asserted, for example, that 8 F-15s can deliver the same weight of destructive force to a

target as 291 WWII-vintage B-17s. Thus thousands fewer airmen are exposed to hostile fire while lethality remains constant. Likewise, the M-1 tank is regarded by tank crews as a vastly superior weapon system and the crewmembers are not concerned that a few more people are needed on the maintenance team (Ostovich, 1982).

The real problem with technology may be that some sort of ripening phenomenon does need to take place before a given innovation is incorporated into a new weapon system. Such a time-based phenomenon would tie back into the emphasis on speed vs. accuracy. Too much haste might not only lead to design errors but also to the deployment of a weapon system encumbered by an "immature" technology.

While the conceptual concerns are very broad, they do lead finally to the matter of how the HFE/MPT contributions can and should be integrated into the system development process. We can see by the above that the relative neglect of HFE/MPT participation by engineering managers during the past several years can be regarded as symptomatic of a larger set of problems. If speed of development is given priority over the quality of the product, there exists a basic incompatibility: the inclusion of HFE/MPT contributions can be time-consuming and the resultant potential improvement in system quality is irrelevant. Likewise, inclusion of HFE/MPT contributions represent a front-end investment that is incompatible with a strategy of minimal budgetary commitment. Finally, one way to accelerate the maturation of a technology is to expose that technology to the hands-on ministrations of human operators and maintainers. That is what can be done and should be done in a research laboratory setting <u>before</u> the overall system design effort is even begun.

If speed and the reduction of front-end investment costs are and remain the overriding values in the process of military system development, two conclusions seem compelling. One is that the practice of waiving HFE/MPT directives in the early stages of the development process will continue for the simple reason that it is logical to do so. The second is that the lack of intensive linkage between the Service laboratories and the designers will also continue because the laboratories need blocks of unencumbered time in order to produce research findings of quality.

Whether this value orientation is moderated or not--and in any case, it is not universal or overwhelmingly out of balance--the laboratories do have a crucial role to play in supporting the system development process. This role is described below from the point of view that if there are flaws in the developmental process, the work of the laboratories can be directed toward minimizing the negative consequences of such flaws. Sometimes even the best physician must be satisfied with having ameliorated the symptoms rather than achieving a complete cure.

## Toward an Optimum MPT/HFE Program

While the human-related problems in military systems will defy any attempts at simple solution, the implementation of well-conceived, integrated MPT/HFE programs should help to mitigate, if not resolve, many of the human performance deficiencies described earlier. At the present time numerous programs exist in a variety of labs, field units, and systems commands. While many of them undoubtedly are quite good, the literature suggests that there is room for improvement. Thus the discussion below highlights what are perceived by commentators to be among the more crucial (and interdependent) ingredients for a highly effective program.

Basic Research. Studies having wide systems applicability are needed for establishing norms and standards applying to human performance. While a great deal of data have been collected in areas such as anthropometry, for example, other types of data derived from various areas of experimental research could be of great value. For example, the influence of design modifications, procedural requirements, skill levels, etc. upon performance (e.g., error probabilities, speed, etc.) could be examined. The predictability of cognitive functioning in situations that demand abstract intellectual performance, as well as the environmental parameters such as threat/stress that could affect cognitive processes, should be studied.

Data Base Assembly. As data are generated, the need arises for better ways of organizing such data and enhancing utilization. Presently, there exists no coherent picture of the HFE and MPT laboratory data which have been collected. The same is true for much of the existing field data. What is missing and sorely needed is a comprehensive data base which consolidates such data and permits retrieval when and where such data are needed. Both system developers and HFE/MPT field units would profit from the ability to call up data which, for example, would inform them of the most likely effects of changing skill levels, crew size, etc. upon subsystem or system performance, along with generating costs estimates of remedial action.

Development of Methodology. Inadequacy of present methodology in the human resource planning areas has been the thrust of much criticism. In particular, the ability to accurately forecast manpower requirements has been a problem, one which has been exacerbated by simultaneous shifts in manpower availability (e.g., as a consequence of changing

civilian unemployment levels) and systems requirements/characteristics. Clearly, in order to attain a reasonable degree of accuracy, such methodologies must incorporate all of the personnel subsystem and design variables which substantially influence personnel requirements. Also, other methodologies should be explored for their potential utility; for example, the integration of life-cycle cost analytical techniques with human resources models such as HARDMAN should be considered.

Also, task analytic techniques should be upgraded in order to improve their applicability in performance areas where the critical behaviors are increasingly less tangible (decision-making, diagnostics, etc.). Finally, the data obtained through the use of all effective methodologies should become part of an easily accessed data base, as discussed above.

Direct Systems Support. Much of what HFE/MPT personnel should do in direct support of systems development is well documented. An abbreviated listing of those responsibilities and activities of systems staff in this context is as follows: participation in early design decisions; the determination of optimal man-machine allocational trade-offs; the analysis of tasks (skill levels, workflow, layout, etc.); the development of detailed MPT/HFE requirements; and the evaluation of man's effectiveness within the system.

Certain activities which fit within this framework need bolstering. The participation of representatives from the behavioral sciences in (S)SARC and DSARC reviews should increase and, if possible, be formalized. Finally, one of the most important but often deficient areas of endeavor is that of requirements determination. System designers need more extensive

inputs from the combat and other field units both with respect to deficiencies of existing systems and the changing nature of the threat as it is perceived by the rank and file who must confront that threat on a day-to-day basis.

## Summary

While specific weapon systems are often the targets of critical concern by commentators, it is the process of military system development that needs continuing attention. The present climate tends to emphasize developmental pace, tight control of front-end investment and hyper-sophisticated machine technology. This climate is not conducive to the optimum mode of contribution from the HFE/MPT community. While technological sophistication is probably not the "problem" and, indeed, can be its own "solution," the HFE/MPT community should probably posture itself to support and improve the development process in spite of the adverse circumstances. This posture should reflect two main emphases: the provision of better analytical tools to HFE/MPT practitioners and the engineering managers for whom they work; and the provision of more data in more accessible forms on the matters of human resource needs, operational requirements, and operational deficiencies of existing systems.

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